Appendix C
Uplift

C-1. Purpose

Uplift pressures depend a great deal on site geology, as well as on engineering features such as foundation grouting, drainage, cutoffs, and impervious blankets, which are used to reduce seepage and uplift pressures. Uplift assumptions are valid only if there is adequate resistance to piping. If there is a concern about piping, geotechnical engineers should be consulted. Uplift loads and the effect various man-made engineering features have on foundation uplift pressures are discussed in Chapter 4. The purpose of Appendix C is to provide, for convenience and easy reference, a summary of Corps design uplift requirements as they apply to gravity dams, spillway chutes, navigation locks, and other miscellaneous structures. These design uplift requirements will produce conservative designs under most geologic site conditions.

C-2. General

Uplift due to hydrostatic pressure at the junction between the structure and its foundation must be considered. The permeability of the foundation soils, or for rock foundations, the permeability of joints, faults, and shear zones in the foundation, greatly affect uplift pressures. Therefore, close coordination with geotechnical engineers is needed in determining uplift pressures. Drainage can be used effectively to reduce uplift pressures. The uplift pressure at any point under the structure will be dependent on the presence, location, and effectiveness of foundation drains. Cutoffs such as grout curtains, impervious blankets, sheet-pile walls, and keys also affect uplift pressures and should be considered in determining design uplift pressures and drainage requirements. Seepage flow net and creep theory can be used to determine uplift pressures for structures on soil foundations. Figures 5-1, 5-2, and 5-3 in Chapter 5 illustrate the creep theory for a retaining wall, a keyed floodwall, and a floodwall with sheet-pile cutoff that are founded on soil. The fundamental design principles and guidance concerning seepage are detailed in EM 1110-2-1901. Uplift pressure is an active force that must be included in the stability and stress analysis to ensure structural adequacy. The uplift pressure will be considered as acting over 100 percent of the base. Uplift pressures are assumed to be unchanged by earthquake loads.

C-3. Drainage

The beneficial effects of drains are that they reduce the water pressure acting on structures and tend to prevent piping in soil foundations. Backfill drains decrease lateral water pressure and uplift acting on a structure by lowering the water table. Foundation drains for structures on rock foundations are often critical in providing stability. For new designs, assumed water pressures for stability analyses should be based on working drainage conditions. For existing structures, water pressures may need to be considered for both working and clogged drains, depending on actual measured conditions.

C-4. Design Uplift Guidance for Gravity Dams

a. General. A hydraulic gradient between the upper and lower pool is developed between the heel and toe of the dam. The pressure distribution along the base and in the foundation is dependent on the effectiveness of drains and grout curtain, where applicable, and geologic features such as rock permeability, seams, jointing, and faulting. The uplift pressure at any point under the structure will be tailwater pressure plus the pressure measured as an ordinate from tailwater to the hydraulic gradient between upper and lower pool.

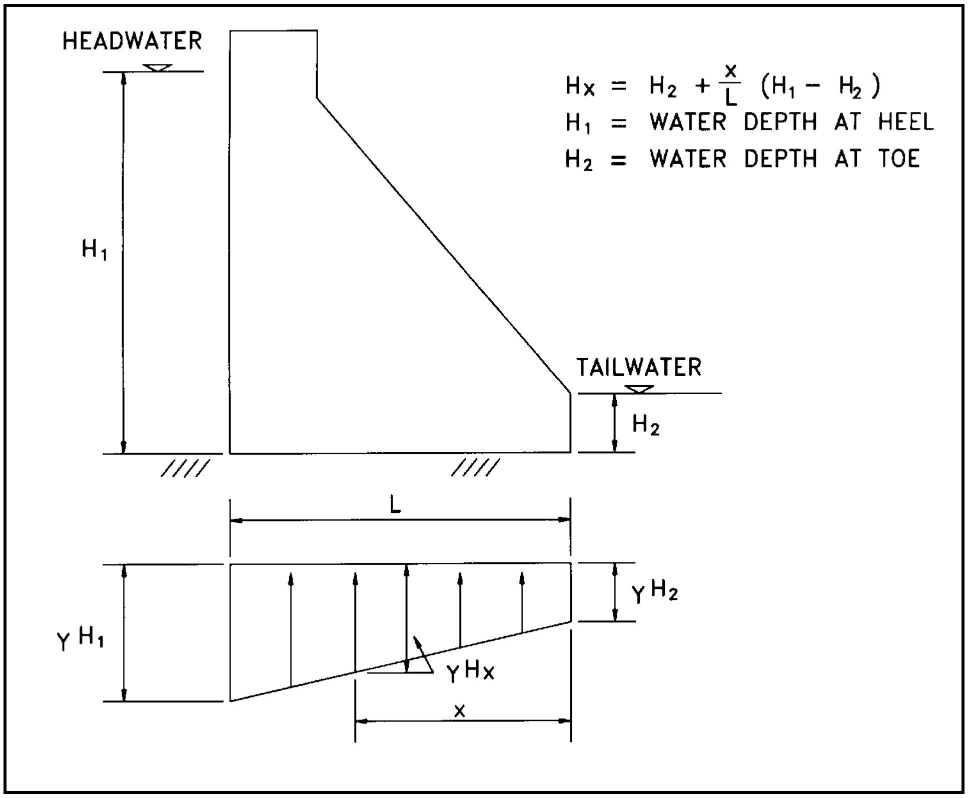

Figure C-1. Uplift distribution without foundation drains

b. Without drains. Where there have not been any provisions provided for uplift reduction, the hydraulic gradient will be assumed to vary, as a straight line, from headwater at the heel to zero or tailwater at the toe. Determination of uplift, at any point on or below the foundation, is demonstrated in Figure C-1.

c. With drains. Uplift pressure at the base or below the foundation can be reduced by installing foundation drains. The effectiveness of the drainage system will depend on the depth, size, and spacing of the drains; the character of the foundation; and the facility with which the drains can be maintained. The assumed effectiveness will be limited to no greater than 50 percent, and the design documentation should contain supporting data to justify this assumption. If foundation testing and flow analysis provide supporting justification, the drain effectiveness can be increased beyond 50 percent with approval from CECW-ED. This criterion deviation will depend on the pool-level operation plan, instrumentation to verify and evaluate uplift assumptions, and an adequate drain maintenance program. Along the base, the uplift pressure will vary linearly from the undrained pressure head at the heel, to the reduced pressure head at the line of drains, to the undrained pressure head at the toe, as shown in Figure C-2. Where the line of drains intersects the foundation within a distance of 5 percent of the reservoir depth from the upstream face, the uplift may be assumed to vary as a single straight line, which would be the case if the drains were exactly at the heel. This condition is illustrated in Figure C-3. If the drainage gallery is above tailwater elevation, the pressure at the line of drains should be determined as though the tailwater level is equal to the gallery elevation.

d. Grout curtain. For drainage to be controlled economically, retarding flow to the drains from the upstream head is mandatory. This may be accomplished by a zone of grouting (curtain) or by the natural imperviousness of the foundation. A grouted zone (curtain) should be used wherever the foundation is amenable to grouting. Grout holes shall be oriented to intercept the maximum number of rock fractures to maximize its effectiveness. Under average conditions, the depth of the grout zone should be two-thirds to three-fourths of the headwater-tailwater differential and should be supplemented by foundation drain holes with a depth of at least two-thirds that of the grout zone (curtain). Where the foundation is sufficiently impervious to retard the flow and where grouting would be impractical, an artificial cutoff is usually unnecessary. Drains, however, should be provided to relieve the uplift pressures that would build up over a period of time in a relatively impervious medium. In a relatively impervious foundation, drain spacing will be closer than in a relatively permeable foundation.

e. Zero compression zones. Uplift on any portion of the foundation plane not in compression shall be 100 percent of the hydrostatic head of the adjacent face, except where tension is the result of instantaneous loading resulting from

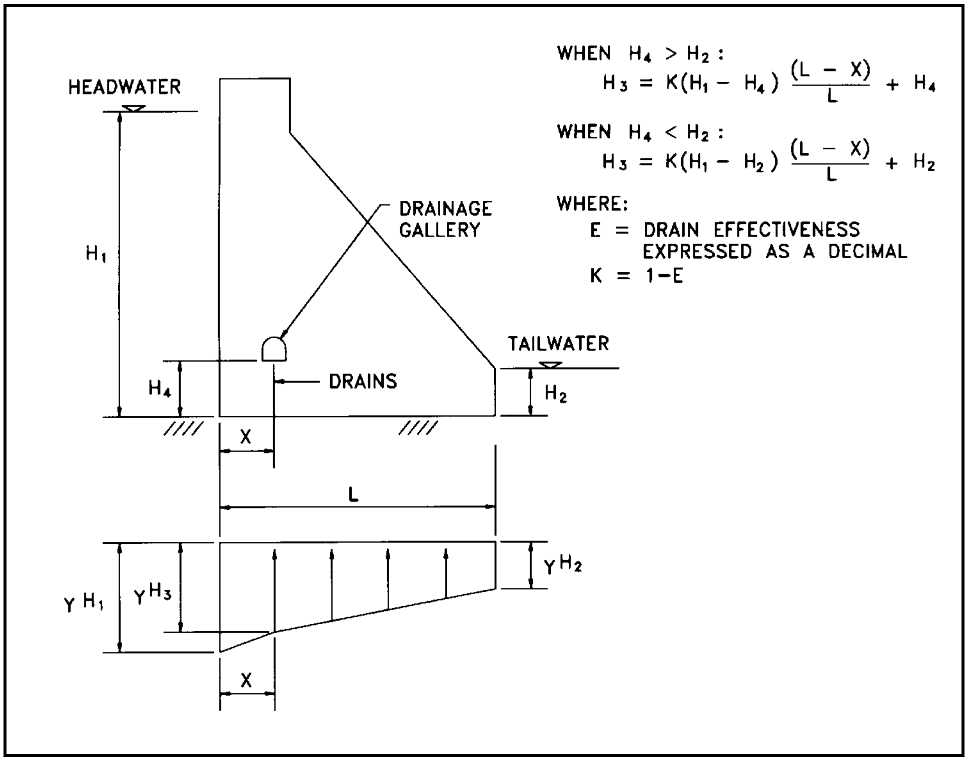

Figure C-2. Uplift distribution with drainage gallery

earthquake forces. When the zero compression zone does not extend beyond the location of the drains, the uplift will be as shown in Figure C-4. For the condition where the zero compression zone extends beyond the drains, drain effectiveness shall not be considered. This uplift condition is shown in Figure C-5. When an existing dam is being investigated, the design office should submit a request to CECW-ED for a deviation if expensive remedial measures are required to satisfy this loading assumption. Refer to Chapter 7 for additional discussion.

f. Nonoverflow sections. The uplift pressure at the heel of a nonoverflow section will be determined using the full tailwater depth as described in paragraphs C4-1(b) and C4-1(c).

g. Overflow sections. For overflow sections, tailwater pressure must be adjusted for retrogression when flow conditions result in a significant hydraulic jump in the downstream channel, i.e., spillway flow plunging deep into tailwater. The forces acting on the downstream face of overflow sections due to tailwater may fluctuate significantly as energy is dissipated in the stilling basin. Therefore, these forces must be conservatively estimated when used as a stabilizing force in a stability analysis. Studies have shown that the influence of tailwater retrogression can reduce the effective tailwater depth used to calculate pressures and forces to as little as 60 percent of the full tailwater depth. The amount of reduction in the effective depth used to determine tailwater forces is a function of the degree of submergence of the crest of the structure and the backwater conditions in the downstream channel. For new designs, EM 1110-2-1603 provides guidance in the calculation of hydraulic pressure distributions in spillway flip buckets due to tailwater conditions. When tailwater conditions significantly reduce or eliminate the hydraulic jump in the stilling basin, tailwater retrogression can be neglected and 100 percent of the tailwater depth can be used to determine tailwater forces. Full tailwater depth will be used to calculate uplift pressures at the toe of the structure in all cases, regardless of overflow conditions. Figure C-6 illustrates the forces and uplift pressures to be used in stability analysis for an overflow and stilling basin section operating under hydraulic jump conditions.

C-5. Design Uplift Guidance for Navigation Locks

a. General. The problem of uplift for lock walls is complicated by fluctuating water levels within a lock chamber. The rate of change of uplift as the chamber is filled or emptied is not known. The design uplift assumptions used for the stability analysis of lock structures is described in the following paragraphs.

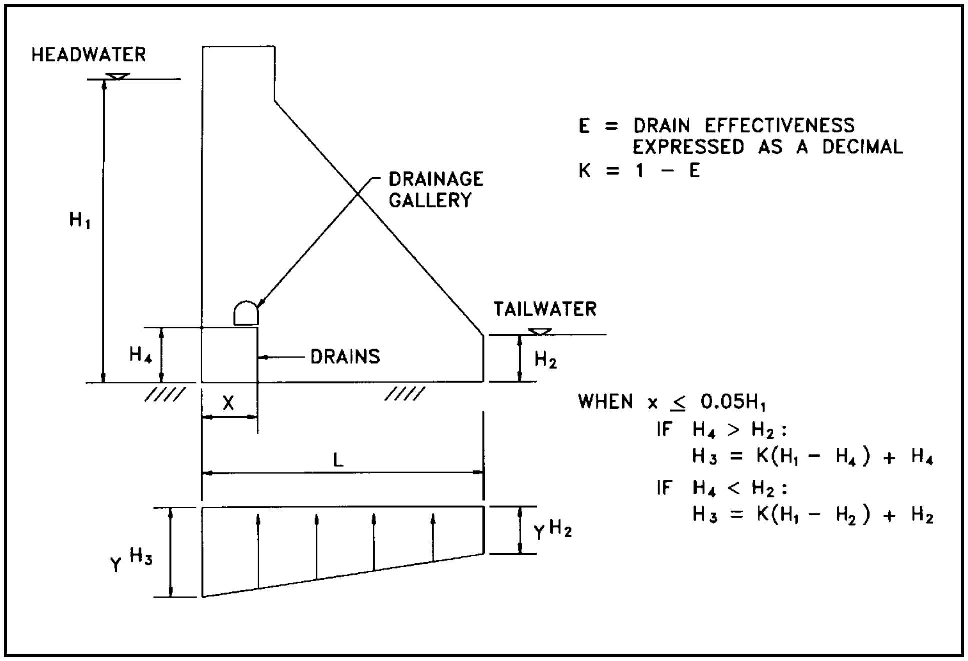

Figure C-3. Uplift distribution with foundation drains near upstream face

b. Rock foundations. During construction, uplift acting on the base of any monolith within the cofferdam is assumed to be zero. For any operating condition, uplift will vary linearly from the chamber face to the opposite face; uplift at each face will be 100 percent of the water elevation adjacent to that face (either the current chamber water elevation, the river water elevation or the saturation line in the backfill). In cases where adequate drainage (relieving to tailwater) is provided near the chamber face, total uplift may be reduced for the condition of upper pool in the lock chamber. For river walls, uplift will vary from 100 percent of tailwater plus 50 percent of the difference between headwater and tailwater at the chamber face to 100 percent of tailwater at the river face. For land walls, use the saturation line instead of tailwater. Probably the most effective land wall drainage is that provided in the backfill to reduce the saturation level.

c. Soil and pile foundations. Monoliths on soil or pile foundations usually have cutoff walls and sometimes have drainage systems. At one face of the monolith, uplift should be the full headwater pressure from the face of the wall to the cutoff. At the other face, uplift equals the full tailwater pressure (or the saturation head in the backfill). Uplift pressures between these points should be determined by evaluations of cutoff and drain effectiveness and soil permeability. Cutoffs and drains will normally be designed for 50 percent reduction in uplift, similar to rock foundations. Under excellent conditions, cutoffs and drains can be considered beyond 50 percent effective in reducing uplift pressures with approval from CECW-ED. Except for earthquake loading, any portion of the base not in compression will be assumed to sustain a uniform uplift equivalent to 100 percent of the adjacent pool or saturation level. Uplift for loadings which include earthquake forces will be assumed to be equal to that for the same loading without earthquake forces. Because minor movements of gate sills affect the gate operations, all sill blocks should be analyzed for stability and for internal stresses resulting from maximum differential heads. Uplift on the sills should be determined similar to the lock walls. The uplift under U-frame locks is complicated by alternative seepage paths along and perpendicular to the lock axis. The permeability of the foundation soils, as well as the existence of sheet-pile cutoff walls and foundation drains, effect the variation of the uplift pressure. Close coordination with geotechnical engineers is needed to determine the uplift pressure for each lock monolith. All combinations of operating and maintenance conditions should be analyzed to determine the most critical condition.

C-6. Design Uplift Guidance for Other Structures

The influence that drains and cutoffs have on uplift pressures for other structures such as retaining walls, intake towers, and lined flood-control channels are similar to those described above for gravity dams and navigation locks.

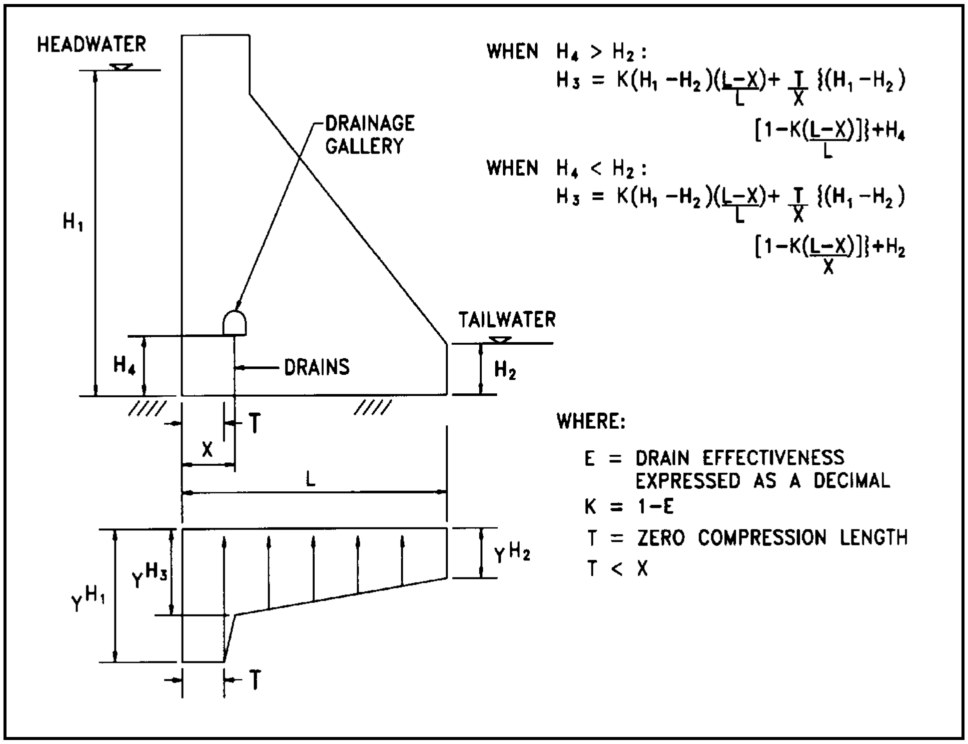

Figure C-4. Uplift distribution for cracked base with drainage, zero compression zone not extending beyond drains

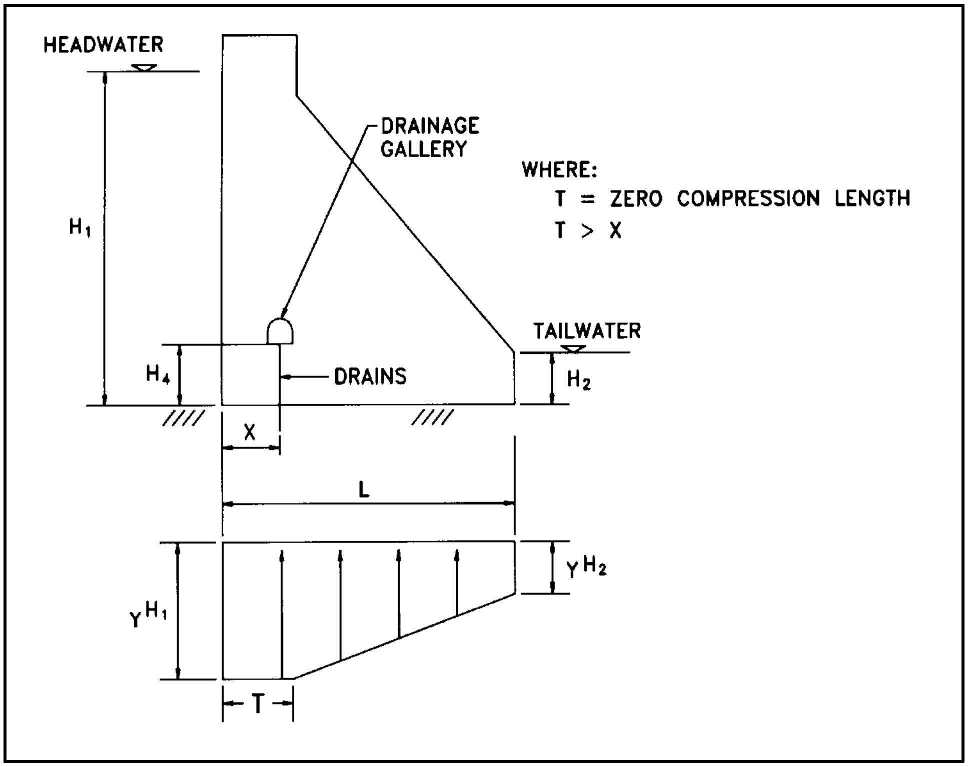

Figure C-5. Uplift distribution for cracked base with drainage, zero compression zone extending beyond drains

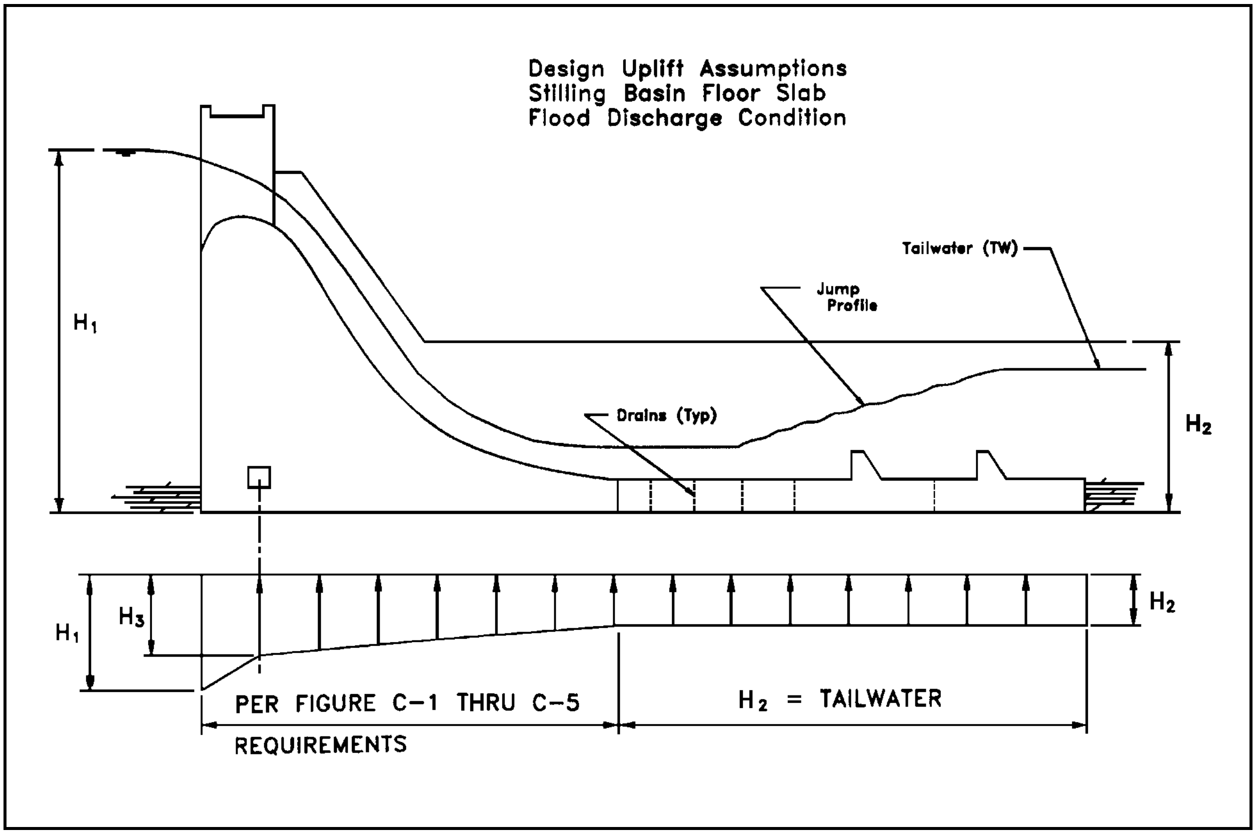

Figure C-6. Stilling basin with discharge condition